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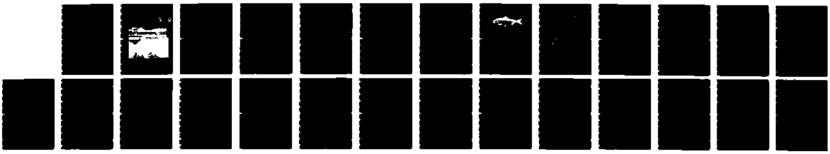

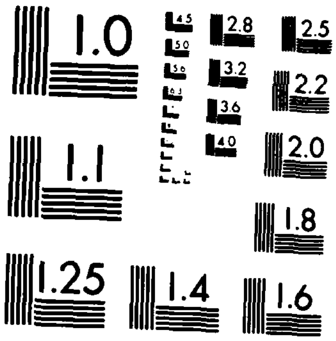

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Biological Report 82(11.45)
April 1986

TR EL-82-4

Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Atlantic)

AMERICAN SHAD

Fish and Wildlife Service
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Coastal Ecology Group
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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Atlantic)

AMERICAN SHAD

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Performed for
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Washington, DC 20240

PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

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or

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CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
acres	0.4047	hectares
square miles (mi^2)	2.590	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees	0.5556(°F - 32)	Celsius degrees

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ACKNOWLEDGMENTS

We thank Ronald J. Essig, Georgia Department of Natural Resources, Brunswick; Nan C. Jenkins, South Carolina Wildlife and Marine Resources Department, Charleston; and John W. McCord, South Carolina Wildlife and Marine Resources Department, Charleston, for reviewing the manuscript. J. Ernest Snell, Supervisory Statistician, National Marine Fisheries Service, Brunswick, Georgia, provided recent data on American shad harvest. Jennifer Biggers prepared Figure 1.

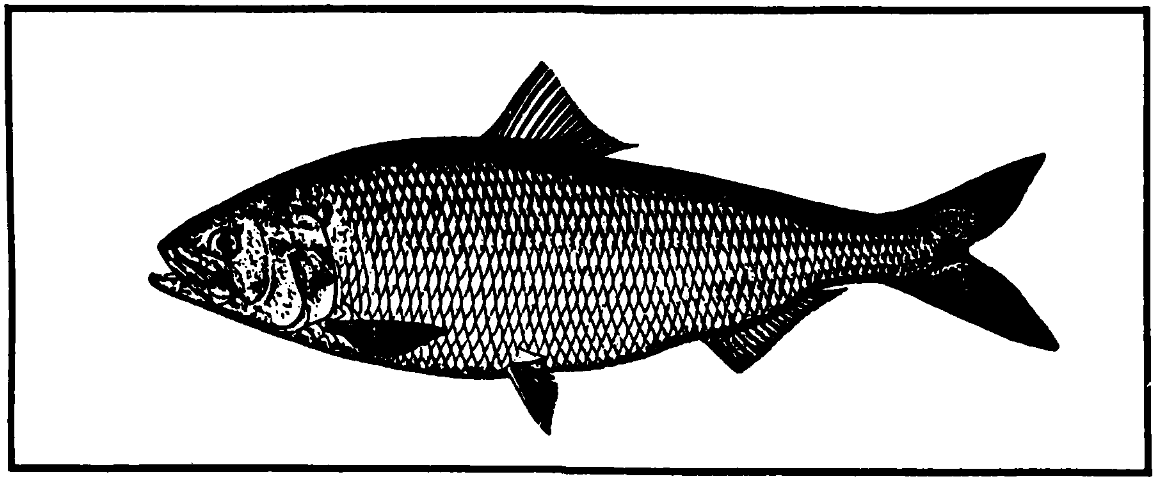

Figure 1. American shad.

AMERICAN SHAD

NOMENCLATURE/TAXONOMY/RANGE

Scientific name . . . . *Alosa sapidissima* (Wilson)
Preferred common name . . . . American shad (Figure 1)
Other common names . . . . shad, white shad, common shad, Atlantic shad, North River shad, Potomac shad, Connecticut River shad, Delaware shad, Susquehanna shad, alose (Scott and Crossman 1973).
Class . . . . Osteichthyes
Order . . . . Clupeiformes
Family . . . . Clupeidae

Geographic range: The American shad is native to the east coast of North America from northern Florida to Newfoundland and is most abundant from North Carolina to Connecticut (Figure 2). The species is anadromous and lives in fresh-, brackish-, and saltwater during its various life stages. American shad were successfully introduced into the Sacramento and Columbia Rivers on the Pacific coast in the late 1800's, and now are established from southern California northward to Cook Inlet, Alaska, and the Kamchatka Peninsula on the Asiatic side of the North Pacific. Attempts to introduce American shad into Lake Ontario, the Mississippi River drainage, peninsular Florida, and Great Salt Lake have not been

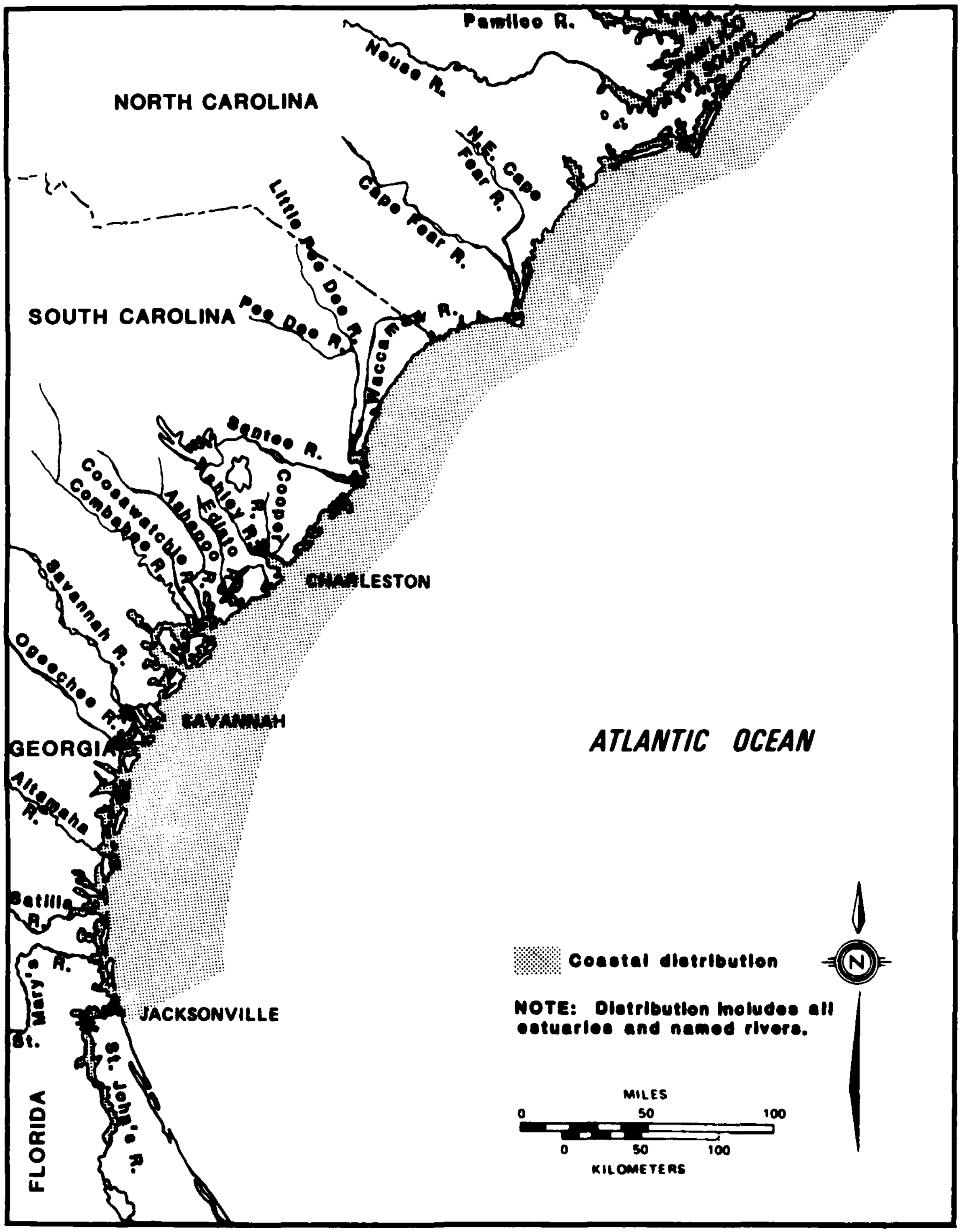

Figure 2. Major spawning rivers of the American shad in the South Atlantic Region.

successful (Scott and Crossman 1973). Millerton Lake, a reservoir on the San Joaquin River in California, supports the only known reproducing landlocked population of American shad (Lambert et al. 1980).

MORPHOLOGY AND IDENTIFICATION AIDS

The following description of American shad is summarized from Hildebrand (1963) and Scott and Crossman (1973).

The American shad is the largest member of the herring family (Clupeidae). Females may reach a total length (TL) of 600 mm and a weight of 5.4 kg. The body is slender and strongly compressed; body depth is 25-38% of standard length (SL) and increases with age. The head is broadly triangular; the gill membranes are entirely free from the isthmus. The maxillary is broad and extends to the middle of the eye in the young, and generally to below the posterior margin of the eye in adults. The gill rakers increase in number and proportionate length with age; adults usually have 59-73 rakers on the lower limb of the first gill arch. Teeth on the jaws and tongue of young shad are lacking in adults. The American shad has one dorsal fin (15-19 rays) of moderate height, a deeply forked caudal fin, and an anal fin with 18-24 rays. There are 35-38 well-developed ventral scutes, 19-23 in front of the pelvic fins and 12-19 behind. American shad have 53-59 (usually 55-58) vertebrae.

Live specimens have a greenish- to bluish-metallic luster on the back and are bright silver on the sides. A dark spot on the shoulder, just behind the posterior edge of the operculum, is usually followed by 3 to 27 smaller spots or dots. There is sometimes a second row of 1 to 16 spots below the first, and rarely a third row of 2 to 9 spots below the second.

The American shad lacks the greatly elongated last dorsal fin ray present in both the gizzard shad (Dorosoma cepedianum) and the threadfin shad (D. petenense). It has more than 55 gill rakers on the lower limb of the first gill arch and usually has at least four black spots in a horizontal row behind the operculum. The congeneric alewife (A. pseudoharengus) and blueback herring (A. aestivalis) have fewer than 55 gill rakers and only one prominent black spot near the upper rear edge of the operculum. The hickory shad (A. mediocris) has 18-23 gill rakers on the lower limb of the first gill arch and it has teeth in the lower jaw at all ages (Dahlberg 1976). In adult American shad, the maxillary extends at least to the posterior margin of the eye, whereas in the alewife and blueback herring it extends only to the midpoint of the eye. Alosa species have a distinct median notch in the upper jaw which separates them from other Clupeid species.

REASON FOR INCLUSION IN THIS SERIES

The American shad has supported major commercial fisheries along the Atlantic coast since the early 1800's and was the most valuable food fish along the east coast before World War II (Rulifson et al. 1982). Commercial landings have declined sharply since the early 1900's; they exceeded 50 million pounds in 1896, but fell to about 2 million pounds in 1976. In many Atlantic coast rivers that still support runs, the sport fishery for American shad has become more important than the commercial fishery.

The decline of American shad has been attributed to dams, overfishing, habitat destruction, and pollution (Sholar 1977; Rulifson et al. 1982). Different factors have been blamed in different river systems and in some instances the combined effects of several factors may be responsible; however, data are too scarce to satisfactorily explain the drastic reduction in the shad population. Because the American shad is an anadromous fish, it is susceptible to perturbations of freshwater, estuarine, and marine habitats, and the needs of the species should be considered in riverine and coastal development projects.

LIFE HISTORY

The life history of American shad on the Atlantic coast was summarized by Walburg and Nichols (1967). Ulrich et al. (1979a) and Rulifson et al. (1982) provided updated life history reviews for the species in the southeastern United States. Much of the information in this section was taken from these two references.

Adult Migration and Spawning

The following offshore migratory patterns for the adult American shad were proposed by Neves and Depres (1979) and are based on field surveys and an extensive review of the literature. In the spring after spawning, adult shad probably migrate to the Gulf of Maine or to an area south of Nantucket Shoals (off southern New England) where they remain through the summer and early fall. These offshore waters are 50 to 100 m deep, and the water temperatures range from 3° to 15° C. In fall and winter, schools of adult fish gradually move southward and overwinter offshore between Long Island and Nantucket Shoals. They also tend to congregate in Middle Atlantic coastal waters during late winter and spring. Shad that were spawned near the northern range of their distribution move northward along the coast as waters warm above 3° C. The south Atlantic populations migrate southward along the coast (within the 15° C isotherm), thereby reaching their home rivers by late winter or early spring.

Most American shad return to their natal streams to spawn. Significant differences in morphological characters among shad from different Atlantic coastal rivers support the belief that there are discrete spawning populations (see Walburg and Nichols 1967). Although this homing tendency is strong, some individuals ascend other rivers to reproduce. The homing behavior of the shad in the Connecticut River may be related to olfaction and orientation to the river current (Dodson and Leggett 1974). These mechanisms probably hold for other shad populations as well.

Water temperature changes are partly responsible for the timing of the spawning migration; most shad enter rivers when water temperatures are betwen 10° and 15° C (Leggett and Whitney 1972). In the St. Johns River, Florida, the migration usually peaks in January when the water temperature is about 15° C (Ulrich et al. 1979a). In general, the peak of the spawning migration becomes progressively later in the year from south to north.

Along the South Atlantic Bight American shad begin their spawning migration in rivers during winter and early spring. They begin to move up the St. Johns River, Florida, as early as November, peaking from mid-January to mid-February (Ulrich et al. 1979a). The spawning run begins in early January in Georgia and South Carolina and in January and February in North Carolina (Ulrich et al. 1979a; Sholar 1977). Some spawning runs may continue as late as April or May. In eastern Canada, some shad do not enter rivers until early June (Walburg and Nichols 1967).

American shad usually spawn in freshwater over substrates of sand, gravel, and mud (Rulifson et al. 1982; Stier, in press). Spawning probably begins in late afternoon or evening and continues until about midnight

(Ulrich et al. 1979a). Diurnal spawning has also been reported in turbid rivers (Chittenden 1976a).

American shad usually spawn at water temperatures of 14° to 21° C (extremes 8° to 26° C) and require dissolved oxygen concentrations of at least 5.0 mg/l (Walburg and Nichols 1967).

The fecundity of American shad varies among natal rivers and the age of the fish. The range is about 100,000 to 600,000 eggs per female (Cheek 1968). Leggett and Carscadden (1978) showed that fecundities along the east coast decreased from south to north (Table 1). The fecundity of shad offshore from North Carolina ranged from 197,000 to 457,000 eggs per female and increased with size and age.

Most American shad from rivers in the southeastern United States die after they spawn, but the occurrence of repeat spawners may exceed 60% in northeastern rivers (Table 2). Reported percentages of repeat spawners are near zero for rivers south of the Neuse River, North Carolina (Table 2). More recent evidence, however, indicates that these rivers may have a few repeat spawners (J. W. McCord, South Carolina Wildlife and Marine Resources Department, Charleston; personal communication). Adults that survive spawning move downriver and migrate to the Gulf of Maine (Walburg and Nichols 1967).

Eggs and Larvae

Unfertilized American shad eggs are pale amber or pink transparent spheres about 1.27 mm in diameter (Ulrich et al. 1979a). After fertilization and water hardening, the diameters increase to about 2.5-3.8 mm (Walburg and Nichols 1967). The eggs are slightly heavier than water, nonadhesive, and require water currents sufficient to buoy the eggs during incubation. Shad eggs generally hatch in 4-6 days at 15°-18° C, but the length of the incubation period depends on water temperature (see ENVIRONMENTAL REQUIREMENTS section for further details).

The larvae of American shad are about 7-10 mm long when they hatch (Walburg and Nichols 1967). On the second or third day after hatching, small teeth appear on the lower jaw and in the pharynx, and the yolk is usually absorbed by the fifth day (Ulrich et al. 1979a). Feeding begins between the 10th and 12th days, and growth is fairly rapid. Larvae develop into juveniles after 4-5 weeks when they are about 25 mm long (Walburg and Nichols 1967).

Table 1. Mean virgin (first spawn) and lifetime fecundities of American shad from five Atlantic coast rivers (Leggett and Carscadden 1978).

Location	Thousands of eggs: Virgin	Thousands of eggs: Lifetime
Miramichi River, New Brunswick	129	258
St. John River, New Brunswick	135	273
Connecticut River, Connecticut	256	384
York River, Virginia	259	327
St. Johns River, Florida	406	406

Table 2. Percent of American shad that spawn more than once in Atlantic coast rivers.

Location	Repeat spawners (%)	Source
St. John River, New Brunswick	73	Leggett and Carscadden (1978)
Connecticut River, Connecticut	63	Leggett and Carscadden (1978)
Hudson River, New York	57	Leggett and Carscadden (1978)
Susquehanna River, Maryland	37	Leggett and Carscadden (1978)
James River, Virginia	27	Leggett and Carscadden (1978)
Chowan River, North Carolina	15	Holland and Yelverton (1973)
Neuse River, North Carolina	7	Hawkins (1980)
Cape Fear River, North Carolina	<1	Fischer (1980)
Edisto River, South Carolina	0	Leggett and Carscadden (1978)
Ogeechee River, Georgia	0	Leggett and Carscadden (1978)
St. Johns River, Florida	0	Leggett and Carscadden (1978)

Juveniles and Adults

Juvenile American shad usually form schools and gradually move downriver at a rate dictated by water temperature and current velocity (Williams and Bruger 1972; Stier, in press). Downstream portions of rivers, tidally influenced freshwater zones, and estuaries are used as nursery areas (Rulifson et al. 1982). Juveniles grow rapidly and commonly exceed 90 mm total length when they begin migrating to the sea (see Rulifson et al. 1982). Emigration from rivers usually begins when water temperatures drop below 15.5° C (Walburg and Nichols 1967), but juveniles in some northern populations may remain in rivers and estuaries throughout the first winter (Stier, in press). In the sea, the juveniles migrate to the Bay of Fundy and then to the Gulf of Maine where they join the adults each summer (Dadswell et al. 1983). They probably move southward and spend the winter in the mid-Atlantic area (Neves and Depres 1979).

American shad from North Carolina become sexually mature when they are 3 to 5 years old (Sholar 1977). Catch data from southern rivers, in which repeat spawners are rare, show that most spawning males are 3-5 years old and most females are 4-6 years old (Loesch et al. 1977; Fischer 1980; Hawkins 1980; Rulifson et al. 1982).

GROWTH CHARACTERISTICS

American shad that spawn in southeastern rivers usually are 3-6 years old and reach 400-525 mm fork length. Because few fish survive to spawn again, their life span is shorter than that of shad in northern populations. The age of American shad can be determined from scales, which show growth rings as well as marks that correspond to spawning migrations (Judy 1961). The average size at a given age is fairly consistent among shad from different rivers in the South Atlantic (Table 3). Females tend to be larger than males of the same age. Holland and Yelverton (1973) predicted age (A) from fork length (FL, cm) for American shad (sexes combined) from offshore North Carolina as:

$$A = 33.86\ FL^{0.17}.$$

Table 3. Age and mean fork length (mm) of American shad caught in rivers of the South Atlantic.

Location	Sex	Age group I	II	III	IV	V	VI	VII	VIII	Source
Pamlico Sound and River, North Carolina	M				404	425	452			Hawkins (1980)
	F				429	464	486	523		
Neuse River, North Carolina	M			375	401	418	435	455		Hawkins (1980)
	F				428	460	482	502	547	
Cape Fear River, North Carolina	M			375	415	439	463			Fischer (1980)
	F				425	466	491	518		
Santee River, South Carolina	M			370	415	425	470			Ulrich et al. (1983)
	F				440	470	500	525		
Savannah River, South Carolina/ Georgia	M				405	445	465			Ulrich et al. (1983)
	F				440	475	505	525		
St. Johns River, Florida	M	175	277	345	394					LaPointe (1958)[a]
	F	180	284	353	409	447				

[a]As cited by Holland and Yelverton (1973).

They also predicted body weight (W, kg) from FL (cm) as:

$$W = (6.84 \times 10^{-6})\ FL^{3.23}.$$

Fork length (cm)-weight (g) regression equations for fish taken from different areas in South Carolina were W = 88.29 FL - 2509.31 for males and W = 111.87 FL - 3390.58 for females (N. C. Jenkins, South Carolina Wildlife and Marine Resources Department, Charleston; personal communication). Regressions by sex for specific river systems in South Carolina were published by Ulrich et al. (1979b). Walburg (1956) found that juvenile shad from six rivers along the Atlantic coast from Florida to Connecticut were similar in size during late summer, even though they spawned earlier in the south than in the north.

COMMERCIAL AND SPORT FISHERIES

Stock Abundance

Historically, the Atlantic coast fishery for American shad has been one of the most important anadromous fisheries in North America (Rulifson et al. 1982). By the mid 1700's, shad supported profitable fisheries from the Chesapeake Bay to Maine. In the early 1800's, access to northern markets was improved by advances in transportation, and shad fisheries became important as far south as Florida. Shad increased in economic importance during the 1800's and supported fisheries in every State along the Atlantic coast. Since the record-setting catch of more than 50 million pounds in 1896, annual landings generally declined. The reported catch for 1976 was about 2 million pounds (NMFS 1980).

Commercial fisheries for shad in southeastern coastal rivers have shown the same historical declines. The North Carolina shad harvest peaked near 9 million pounds in 1896, but declined to less than 200,000 pounds in 1980 (Table 4). The catch in Georgia exceeded 1.3 million pounds in 1908, but was less than 200,000 pounds in 1981. The trend has been the same in South Carolina and Florida. Increased landings after 1977 (see Table 4) may have been partly due to collection of more accurate catch data (e.g., Ulrich et al. 1983).

A survey of licensed shad fishermen in South Carolina showed that less than 5% relied on commercial fishing to make a living, and that even these fishermen derived less than 10% of their annual income from shad fishing (Ulrich et al. 1979a). Most of those surveyed fished only for recreation and home consumption. Among Georgia shad fishermen surveyed during 1980-1982, about 12% indicated that they derived at least 50% of their income

Table 4. Commercial landings (thousands of pounds) and dockside value (thousands of dollars) of American shad in the South Atlantic States, 1960-1962 (Ulrich et al. 1979a; Hawkins 1980; Rulifson et al. 1982; Essig 1983; unpublished data, Georgia Department of Natural Resources and U.S. National Marine Fisheries Service).

Year	North Carolina		South Carolina		Georgia		Florida	
	Landings	Value	Landings	Value	Landings	Value	Landings	Value
1960	507	127	106	34	533	176	468	61
1961	673	168	110	35	404	93	425	70
1962	765	191	115	32	527	132	760	81
1963	693	168	120	33	331	88	590	63
1964	640	127	120	28	314	100	613	60
1965	1069	214	176	61	376	127	758	82
1966	701	170	119	34	386	100	-	-
1967	777	-	132	-	334	-	319	52
1968	842	128	110	21	569	139	531	96
1969	719	137	177	59	618	182	390	61
1970	953	193	148	39	532	140	218	43
1971	680	117	99	40	420	133	253	50
1972	468	112	159	45	344	112	120	27
1973	321	85	26	12	239	91	99	27
1974	369	106	24	12	162	63	100	24
1975	241	83	62	37	182	99	33	9
1976	167	65	32	20	93	57	28	-
1977	121	55	80	54	118	84	97	-
1978	402	145	287	197	238	113	131	-
1979	278	122	197	155	268	-	115	-
1980	199	88	271	215	188	172	181	-
1981	352	190	446	283	196	148	241	-
1982	412	183	243	198	198	166	181	-

income from some form of commercial fishing (Essig 1983).

The major shad-producing rivers in North Carolina are the Tar-Pamlico, the Cape Fear, the Northeast Cape Fear, the Chowan, and the Neuse. At one time, the Neuse River was considered to be the most important shad stream between the St. Johns River, Florida, and the James River, Virginia (Walburg and Nichols 1967; Rulifson et al. 1982). The principal shad producing area in South Carolina is Winyah Bay and its major tributaries, the Waccamaw and Pee Dee Rivers (Ulrich et al. 1979a). Other waters supporting shad fisheries are the Santee River, Charleston Harbor (and its tributaries, the Cooper and Ashley Rivers), the Edisto River, and the Combahee, Ashepoo, and Coosawhatchie Rivers. The Savannah River supports shad runs that benefit fishermen from both South Carolina and Georgia. Besides the Savannah River, Georgia shad fishermen use the Ogeechee, Altamaha, Satilla, and St. Marys Rivers. The Altamaha now supports Georgia's largest shad fishery (Michaels 1980), followed closely by the Savannah River fishery (Essig 1983). Most shad fishing in Florida is in the St. Johns River.

Gear

From about 1960 to 1970, North Carolina shad fishermen primarily used drift and anchored gill nets (56%), pound nets (41%), and haul seines (3%) (Sholar 1977). The predominant gear at the turn of the century was pound nets. Gill nets have recently become the major gear because of the increased efficiency of nylon monofilament twine and low cost compared to pound nets and seines (Sholar 1977).

Shad fishermen in South Carolina have used a variety of fishing gear over the years. Gill nets have been used since the late 1800's. Seines, dip nets, cast nets, and fyke nets have been popular with some fishermen at one time or another, but drift and set gill nets are now the only gear fished commercially (Ulrich et al. 1979a).

Gill nets also have been the preferred gear of shad fishermen in Georgia since the late 1800's; bow nets, pound nets, and fyke nets also have been used. Since the 1960's, commercial shad fishing in Georgia has been primarily accomplished with gill nets; drift gill nets are preferred over set gill nets. Drift gill nets accounted for 82% of the Georgia shad landings in 1979-1982 (Essig 1983). Some fishermen still use hand lines and otter trawls.

Commercial shad fishing in Florida is restricted to gill netting and angling (Capt. L. Shelfer, Florida Marine Patrol, personal communication).

Management

In North Carolina, fishing for American shad is heaviest in January through April; there are no closed seasons (Rulifson et al. 1982). The open season for shad fishing in South Carolina varies somewhat among the rivers, but generally fishing is legal from February 1 to April 30 (Ulrich et al. 1979a). The season in Georgia is closed from May 1 through December 31. The open season is established each year by the Commissioner of Natural Resources, within the period January 1 - April 30 (R. J. Essig, Georgia Department of Natural Resources, personal communication). Florida waters are closed to shad fishing between March 15 and November 15, and the open season generally extends from December 31 to March 1 (Capt. L. Shelfer, Florida Marine Patrol; personal communication).

The minimum legal mesh size for commerical gill netting of American shad in South Atlantic States is between 11.4 and 14.0 cm (stretch mesh). Regulations controlling the number and length of nets and legal fishing hours and days vary within and among river systems.

The Sport Fishery

Sport fishing for American shad with hook and line is common in the Cape Fear and Tar Rivers in North Carolina (Sholar 1977). In late winter, drift gill netting for American shad, hickory shad, and blueback herring is a popular sport in the Neuse River, North Carolina (Hawkins 1980). Sport fishermen in South Carolina and Georgia often fish for American shad with small artificial lures such as shad darts or small spoons (Ulrich et al. 1979a). Bow nets also are used for sport fishing in South Carolina and Georgia. The American shad has become a popular sport fish in some Florida rivers, particularly the St. Johns (Williams et al. 1975).

Population Dynamics

Selective fishing for females and general overexploitation are problems in many rivers along the South Atlantic States. Mature female shad ("roe" shad) are worth about twice as much per pound as males ("buck" shad) because the eggs are highly sought as food by consumers (Ulrich et al. 1983). Fishermen typically direct their fishing toward the more valuable roe shad, which could reduce egg production and potential recruitment. This selectivity for females also biases estimates of population sex ratios that are based on commercial catch statistics. Samples of shad taken by haul seine in the Northeast Cape Fear River indicated a male:female ratio of 4.7:1. Sholar (1977) suggested that the fishery may be overexploiting the females.

Overexploitation of females could seriously affect recruitment in future years. In the Connecticut River, 64% of the annual variation in juvenile shad production was related to the number of adults reaching the spawning grounds (Marcy 1976). Leggett (1976) related the number of adults that reached spawning grounds in the Connecticut River with recruitment in the next year as:

$$R = Ne^{0.7118(1-N/86.59)},$$

where N was the number of eggs produced by the parent stock, and R was recruitment.

Shad harvest in the southeastern states generally includes males that are 4-5 years old and females 5-6 years old (Table 5). However, in the Altamaha River, Georgia, and the St. Johns River, Florida, 3-year-old males contribute a major share of the catch. Rates of annual fishing mortality for American shad vary from 15% to 66% in southeastern rivers (Table 6).

ECOLOGY

Feeding

American shad consume a variety of invertebrate organisms; small fishes are an important part of the diet in some areas. Shad larvae (14-28 mm long) in the Connecticut River above Holyoke Dam, Massachusetts, mainly consumed cyclopoid copepods, midge larvae, midge pupae, and Daphnia pulex (Levesque and Reed 1972). Juveniles in the same area ate crustacean zooplankton, midge larvae and pupae, caddis fly larvae, and adult insects. These findings led Levesque and Reed (1972) to conclude that juvenile shad probably are opportunistic feeders, although they select most of their food from the water column, rather than from the bottom or near the surface.

The stomach contents (volume) of juvenile shad in two tributaries of the York River, Virginia, were 1% amphipods, 28% aquatic insects, and 71% terrestrial insects (Massmann 1963). The mean volume of food per individual shad was seven times

Table 5. Age composition (%) of American shad populations in rivers of the South Atlantic Bight.

River system and year	Sex	Age group II	III	IV	V	VI	VII	VIII	Source
Albemarle Sound	M		1	18	64	13	3		Johnson et al.
1978	F			4	56	39	<1		(1978)
Neuse River	M		5	39	46	9	1		Hawkins (1980)
1977-1979	F			6	58	34	1	1	
Cape Fear River	M		1	59	39	1			Fischer (1980)
1978-1979	F			18	43	36	3		
Waccamaw-Pee Dee	M		<1	9	68	23			Ulrich et al.
drainage 1982	F			<1	27	68	4		(1983)
Edisto River	M			13	83	4			Ulrich et al.
1982	F			4	43	49	5		(1983)
Savannah River	M			7	80	14			Ulrich et al.
1982	F			<1	46	50	33		(1983)
Altamaha River	M		13	49	36	2	<1		Godwin (1968)
1967-1968	F		<1	26	62	11	<1	<1	
St. Johns River	M		23	72	3	2			Williams et
1973	F	<1	2	66	16	14	<1		al. (1975)

Table 6. Fishing mortality rates of American shad in southeastern rivers (from Rulifson et al. 1982).

River system	Year	Mortality (%)	Source
Neuse River, North Carolina	1957	65.0	Walburg (1956)
Waccamaw-Pee Dee	1974	33.9	Crochet et al.
system, South Carolina	1975	29.0	(1976)
	1976	18.5	
Edisto River, South Carolina	1955	20.0	Walburg (1956)
Ogeechee River, Georgia	1954	66.0	Sykes (1956)
Altamaha River, Georgia	1967	48.6	Godwin (1968)
	1968	43.3	
St. Johns River, Florida	1960	15.0	Walburg (1960)

greater at upriver stations, where terrestrial insects were the predominant food, than at downriver stations, where aquatic insects were the principal food. Massmann (1963) cautioned against estimating potential fish production solely from data on plankton and benthos because the most important prey in his study came from wooded areas bordering the river and not from the river itself. Walburg (1956) compared the food of juvenile shad caught during August from the St. Johns River, Florida, Ogeechee River, Georgia, Neuse River, North Carolina, Pamunkey River, Virginia, Hudson River, New York, and the Connecticut River, Connecticut. Insects and crustaceans were the primary food (by frequency of occurrence) in all rivers. Juvenile shad also eat small fishes. Of 15 juveniles (87-141 mm long) caught off the North Carolina coast, 12 had at least one striped anchovy (Anchoa hepsetus) in their stomachs (Holland and Yelverton 1973). Juvenile shad (73-88 mm long) from the St. Johns River, Florida, fed on the larvae of bay anchovies (Anchoa mitchelli) and mosquitofish (Gambusia affinis) (Williams and Bruger 1972). Juvenile shad begin feeding in the late afternoon; feeding intensity is greatest during the early evening and declines from midnight to midday (Massmann 1963; Levesque and Reed 1972).

When adult American shad are offshore, they are believed to be planktivorous, consuming mainly copepods, mysids, and other zooplankters (Hildebrand 1963; Vinogradov 1981; Rulifson et al. 1982; Stier in press). The stomachs of all 41 adults caught off the coast of North Carolina contained zooplankton, including amphipods, copepods, isopods, cumaceans, and larval decapods (Holland and Yelverton 1973). Fish remains in 39 stomachs indicated that adult shad are not exclusively planktivorous. Vinogradov (1981) showed that the types of zooplankton eaten by adult shad in Nantucket Shoals varied with the time of day. Adult shad usually do not feed while migrating upstream to spawn (Rulifson et al. 1982; Chittenden 1976b).

Potential Competitors

Domermuth and Reed (1980) evaluated the potential for food competition among sympatric juvenile American shad, juvenile blueback herring, and pumpkinseed sunfish (Lepomis gibbosus) in the Connecticut River, Massachusetts. They reported that prey selection or foraging locations differed among the species. Pumpkinseeds ate mainly benthic prey and were, therefore, not directly competing with the clupeids, which fed mainly on plankton and drift organisms. Cladocerans made up nearly 30% (by volume) of the stomach contents of the shad and 47% of the diet of the herring, but competition was probably light because the two clupeids tended to consume cladocerans from different families. Copepods made up less than 2% of the diet of shad but nearly 18% of the diet of herring.

Chironomid larvae and pupae made up 53.2% and 35.0% of the diet of shad and herring, respectively, but since chironomids were highly abundant in the river, the sharing of this food resource by shad and herring probably had no adverse effect on either species. Terrestrial adult insects contributed 15% of the shad diet, but were not present in the stomachs of herring. Herring apparently fed only in the water column, whereas shad fed at the water's surface as well as in the water column.

Predators and Diseases

Larval and juvenile American shad probably fall prey to a variety of predators. Young shad are eaten by American eels (Anguilla rostrata) and striped bass (Morone saxatilis) (Walburg and Nichols 1967). Once shad enter the ocean, they are probably eaten by a variety of offshore predators, including sharks, tuna, and porpoises (Walburg and Nichols 1967). Adult shad in rivers seem to have few predators.

Shad are relatively free of severe parasitic infestations. Nematodes, sea lice (isopods), roundworms, trematodes, and acanthocephalans are common parasites. Sea lampreys (Petromyzon marinus) and freshwater lampreys (Ichthyomyzon spp.) have been observed attached to adult shad in the Connecticut River (Walburg and Nichols 1967; Rulifson et al. 1982).

ENVIRONMENTAL REQUIREMENTS

Temperature

Water temperatures are critical to American shad during their life cycle. Most spawn at water temperatures between 14° and 21° C; extremes were 8° and 26° C (Walburg and Nichols 1967). Leggett and Whitney (1972) reported maximum survival of eggs and larvae at 15.5-26.6° C. Leim (1924) reported that temperatures of 7° - 9° C were lethal to eggs and larvae and that temperatures of 20.0° - 23.4° C caused extensive larval abnormalities. The lower thermal tolerance limit of juvenile shad has been reported as 2°-4° C (Rulifson et al. 1982). Below 6° C, juveniles lost equilibrium, ceased feeding, and moved slowly (Chittenden 1972). Young shad can sense and avoid potentially lethal temperatures (Moss 1970). Shad have been collected offshore at water temperatures from 3° to 15° C, but most live in a temperature range from 5° to 13° C (Neves and Depres 1979).

Salinity

Although American shad eggs are deposited and hatch in freshwater, some can tolerate moderate salinities. Eggs were successfully hatched in salinities ranging from 7.5 parts per thousand (ppt) at 12° C to 15 ppt at 17° C. No eggs hatched at a salinity of 22.5 ppt. Juvenile shad can tolerate sharp salinity changes, which allows them to use both freshwater and brackish waters as nursery areas (Chittenden 1973). Adults move from saltwater to freshwater during their spawning migration, typically remaining in estuaries for 2-3 days. Adult shad moved directly from saltwater to freshwater started to die after 5 hours (Leggett and O'Boyle 1976).

Dissolved Oxygen

American shad usually spawn in flowing water at dissolved oxygen (DO) concentrations exceeding 5.0 mg/l (Walburg and Nichols 1967). DO of at least 4.0 mg/l is necessary in spawning areas (Chittenden 1973). Shad eggs in the Neuse River, North Carolina, were found in waters with oxygen concentrations between 6 and 10 mg/l (Hawkins 1979). Mortality of eggs and larvae exposed to DO concentrations of 2.5 to 2.9 mg/l was about 50% (Stier, in press), and mortality of eggs was 100% at DO's below 1.0 mg/l (Carlson 1968). Larvae lost equilibrium at a DO of 3.0 mg/l; many died at DO's below 2.0 mg/l; and all died at 0.6 mg/l (Chittenden 1969). Juvenile shad seem to prefer high DO concentrations when exposed to a gradient but can probably survive low DO (0.5 mg/l) for several minutes if they have access to DO above 3.0 mg/l (Dorfman and Westman 1970). Minimum DO's of 2.5 - 3.0 mg/l are probably sufficient to allow juvenile migration through polluted waters (Chittenden 1973). Severely low DO concentrations in rivers can prevent the passage of adult shad to spawning areas upstream (Rulifson et al. 1982).

Water Movement

Proper development of shad eggs requires water velocities that keep the eggs suspended in the water (Sholar 1977). Spawning is common in water currents with a velocity from 30.5 to 91.4 cm/sec (Walburg 1960).

Water velocity also affects energy expenditures by adult shad that must move upstream to reach spawning areas (Glebe and Leggett 1981).

Dams block American shad migrations to upstream spawning areas, but several methods can be used to pass or lift the fish over dams. The earliest designs often failed because water depths and flows near fishways did not attract adult shad. Most effective fishways collect fish moving into one or several entrances and direct them to a single fish-passage facility. Walburg and Nichols (1967) reviewed the history and efficiency of shad fishways along the Atlantic coast; information in the remainder of this section comes from their report.

Fishway collection systems for shad should be at least 1.2 m deep and 2.4 m wide. Water velocities should not exceed 1 m/sec. The entrances to the collection system should be at least 1.8 m wide and have a depth of at least 0.3 m, preferably 1.0 m. The velocity at the entrance should be 1.5-2.1 m/sec.

After shad have been attracted into the collection system, several methods can be used to pass or lift fish over dams, including elevators, locks, and pool-type fishways. For pool-type fishways, which consist of a series of pools, each higher than the next pool downstream, the difference in pool elevation should be about 0.25 m. Pools should be at least 2.4 m long, 2.4 m wide, and 1.2 m deep, but the size should be increased if large numbers of shad are expected to use the fishway.

Although the present state of engineering and biological knowledge appears to be adequate for providing upstream passage of adults, the problem of safe passage of young and adults back downstream have not been adequately solved. Fish must usually pass through turbines or over spillways, causing considerable mortality.

Turbidity, Substrate, and Depth

Shad eggs exposed to suspended sediment concentrations as high as 1,000 mg/l did not affect hatching success (Auld and Schubel 1978). The mortality of larvae was high at concentrations of suspended sediments greater than 100 mg/l for 96 hours.

American shad may spawn at many different depths and over a variety of substrates. They seem to prefer areas dominated by shallow water or broad flats with a sand or gravel bottom (Mansueti and Kolb 1953; Walburg 1960; Leggett 1976). They also spawn in deeper waters adjacent to shoals (Stier, in press).

At sea, shad tend to remain near the bottom during the day and move up in the water column to feed at night (Neves and Depres 1979). Adults have been found at depths of 20-340 m, but most occur at 50-100 m.

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16. Abstract (Limit: 200 words)

Species profiles are literature summaries of the life history, distribution, and environmental requirements of coastal fishes and invertebrates. Profiles are prepared to assist with environmental impact assessment. The American shad (Alosa sapidissima) was the most valuable food fish on the Atlantic coast prior to the 1940's; but landings have declined drastically since that time, and sport fishing has become more important than commercial fishing in most rivers where stocks still exist. The American shad is anadromous: adults congregate offshore in areas within the North Atlantic Bight during summer, move southward in coastal waters during fall and early winter, and move up rivers to spawn during late winter and spring. In rivers in the South Atlantic Region, the spawning run peaks during January and February, but can continue through April and May. Larval shad live in upriver areas and eat a variety of small invertebrates. Juveniles gradually move downriver and live in estuaries, where they grow to about 100 mm in length and migrate to sea where they live 3-5 years before maturing. Most American shad return to their natal river to spawn; and in the South Atlantic Bight, most adults die after spawning once. Development of eggs requires water temperatures of 14 to 21 °C, dissolved oxygen concentrations of at least 5 mg/l, and current velocities capable of buoying eggs during incubation. Downstream transport of the young and spawning migrations of adults can be adversely affected by excessive alteration of the river flow.

17. Document Analysis a. Descriptors

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